AD-A247 446

USAFETAC/PR--91/022

SIMULATED AND OBSERVED SUNNY LINE-OF-SIGHT PROBABILITIES

at

PALEHUA, HAWAII

by

CAPT ANTHONY J. WARREN

DECEMBER 1991

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REPORT DOCUMENTATION PAGE

2. Report Date: December 1991

3. Report Type: Project report

4. Title: Simulated and Observed Sunny Line-of-Sight Probabilities at Palehua, Hawaii

6. Author: Capt Anthony J. Warren

7. Performing Organization Name and Address: USAF Environmental Technical Applications Center (USAFETAC/DNY), Scott AFB, IL 62225-5438

8. Performing Organization Report Number: USAFETAC/PR--91/022

12. Distribution/Availability Statement: Approved for public release; distribution is unlimited.

13. Abstract: This report documents a study of the differences in the climatological probabilities of a cloud-free line-of-sight (CFLOS) at the Palehua, Hawaii, Solar Optical Observatory and the Barbers Point Naval Air Station, about 5 miles southeast of Palehua. The study shows that sunny line-of-sight probabilities (SLOS--cloud-free line-of-sight from an observer to the Sun) are typically about 10 percent lower at Palehua (elevation about 1,700 feet) than at Barbers Point (34 feet). The study compared 17 years of actual weather observations from Barbers Point and 5 years of Palehua solar optical site status reports (surface weather observations are not available from Palehua). The results of this study suggest that the Stanford Research Institute technique for relating fractional sky-cover and viewing angle to CFLOS probability (described by Malick, et al., 1979) is valid for use in Hawaii.

14. Subject Terms: CLIMATOLOGY, WEATHER, SOLAR OBSERVATIONS, SOLAR OBSERVATORIES, SURFACE WEATHER OBSERVATIONS, WEATHER STATIONS, CLOUD COVER, CLOUD-COVER FREQUENCY, CLOUD-FREE LINE-OF-SIGHT, SIMULATION

15. Number of Pages: 17

17. Security Classification of Report: Unclassified

18. Security Classification of this Page: Unclassified

19. Security Classification of Abstract: Unclassified

20. Limitation of Abstract: UL

Standard Form 298

PREFACE

This report documents work done on a follow-on study to USAFETAC Project #900707, which was in response to a support assistance request from the 4th Weather Wing (4WW/DNC) for the climatological probability of cloud-free line-of-sight at certain existing or potential solar optical sites. The requester needed the data for use in a study that would determine the optimum configuration of the AWS Solar Observation network.

The study compares the probability of "sunny line-of-sight" (SLOS--cloud-free line-of-sight from a ground observer to the Sun) at the Palehua solar optical site (elevation about 1,700 feet) with that at Barbers Point Naval Air Station (elevation 34 feet), about 5 miles southeast.

Real-Time Nephanalysis (RTNEPH) data was of no value here because both locations are in the same RTNEPH grid box. Surface observations are available from Barbers Point, but not from Palehua. Therefore, simulated Barbers Point SLOS probabilities were compared to Palehua SLOS probabilities estimated from Palehua status reports. The study concluded that SLOS probabilities at Palehua are typically about 10 percent lower than those at Barbers Point. The results also suggest that the Stanford Research Institute technique for relating fractional sky-cover and viewing angle to CFLOS probability (described by Malick, et al., 1979) is valid for use in Hawaii.

Project analyst was Capt Anthony J. Warren, USAFETAC/DNY, who wishes to thank Capt John A. Rupp, formerly of USAFETAC/DNY, for writing the program for the simulation model. He also thanks Capt Mary L. Hart, USAFETAC/DNE, who analyzed the Palehua optical site's status reports.

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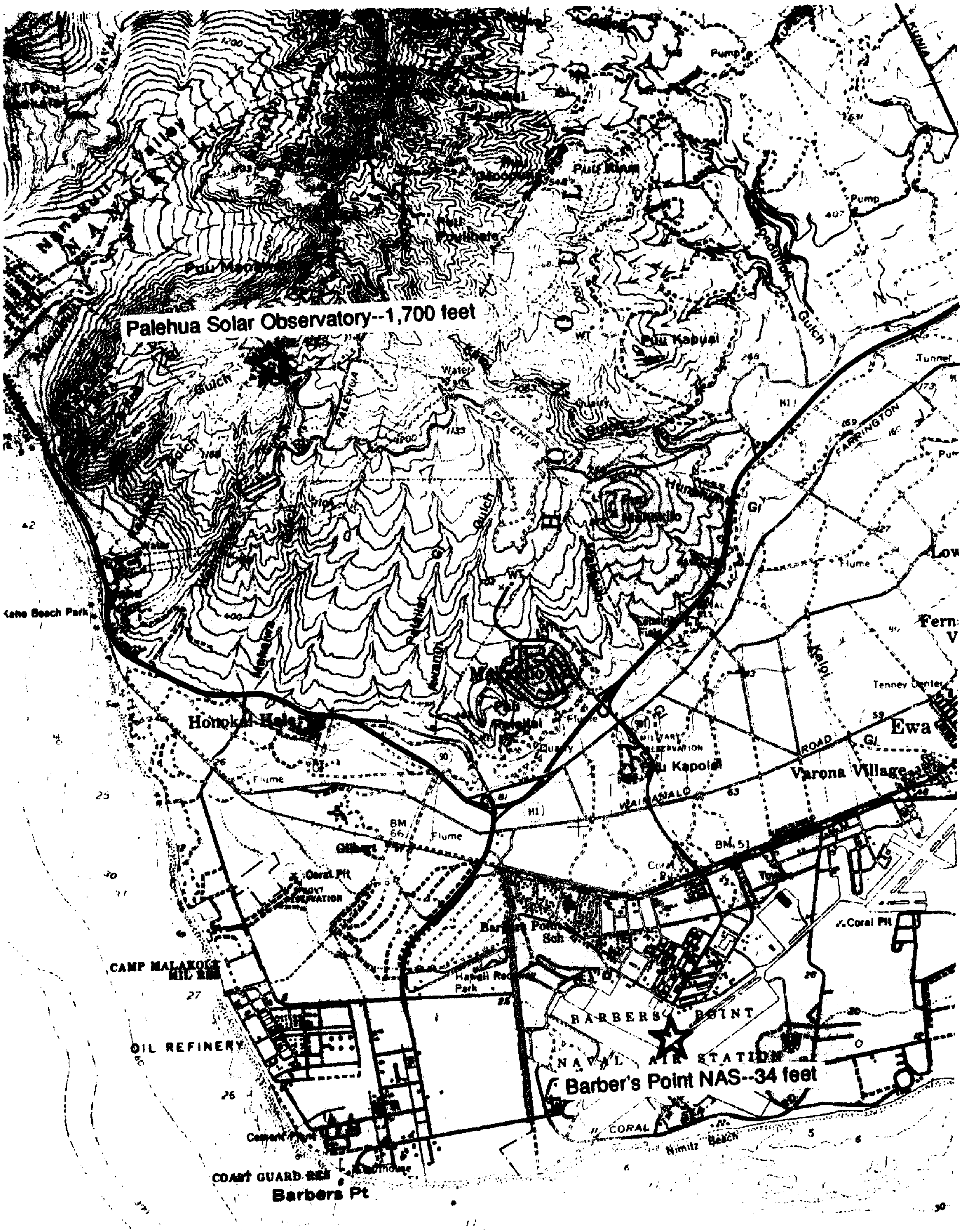

Figure 1. Palehua Solar Observatory location relative tc Barber's Point NAS.

1. INTRODUCTION

1.1 Cloud-Free Line-of-Sight Probabilities. USAFETAC is often tasked to produce cloud-free line-of-sight (CFLOS) probabilities for use in evaluating the effects of clouds on surface-based viewing systems. Since CFLOS is not a weather observation variable, it must be inferred by combining conventional cloud observations with sensor-to-target slant-path geometry. A technique developed at the Stanford Research Institute (SRI) for relating fractional cloud-cover and viewing angle to CFLOS probability is described by Malick et al. (1979). The SRI technique is a refinement of an earlier one developed by Lund and Shanklin (1973). The SRI algorithms are based on a whole sky photograph dataset collected at Columbia, Missouri (Lund and Grantham, 1980). One drawback to this method for computing CFLOS statistics is that very little data is available from other locations. How well the SRI model performs in regions where the cloud climatology differs from Columbia, Missouri, is not well-known.

1.2 CFLOS at Palehua, Hawaii. USAFETAC was tasked to provide the monthly climatological probability of CFLOS at the Palehua, Hawaii, solar observatory. Surface-based cloud-cover statistics are not available for Palehua, but weather observations are made routinely at Barbers Point NAS, about 5 miles to the southeast. See Figure 1, opposite. We computed probabilities from a 17-year period of record (POR) of Barbers Point surface observations. There was no technique for adjusting the elevation difference between Palehua (about 1,700 feet MSL), and Barbers Point (34 feet MSL).

1.3 Observed versus Simulated CFLOS Probabilities. To compare CFLOS probabiities between the two sites we computed the frequency of a sunny line-of-sight from data collected at the solar observatory site. "Sunny line-of-sight" (or "SLOS") is simply a CFLOS between an observer and the Sun. Theoretical SLOS probabilities were then derived from the Barbers Point data. Because of its higher elevation, Palehua is likely to see more cloud-cover than Barbers Point, especially during the afternoon. Despite this difference, the theoretical and observed SLOS probabilities show a high degree of consistency, suggesting that the SRI model is valid for Hawaii.

2. CFLOS ALGORITHM

2.1 The Stanford Research Institute (SRI) Model. Using a whole-sky photograph dataset from Columbia, MO, Lund and Shanklin (1973) derived a matrix for determining CFLOS probability from viewing angle (θ) and observed mean cloud cover (S). The viewing geometry is shown in Figure 2. For a fixed value of mean cloud-cover, the integration of CFLOS probabilities, $P(\theta)$, over the entire sky dome should equal the complement of the mean cloud-cover:

$$S = 1 - \frac{1}{2\pi}\int_0^{2\pi} P(\theta)d\Omega \qquad (1)$$

where Ω represents the solid angle of the sky dome. The Lund and Shanklin model does not conform to this relationship, presumably due to observer bias in reporting cloud-cover. Malick et al. (1979), using basic assumptions of cloud geometry, derived an analytical model for computing CFLOS probabilities. Equations 2 through 4 form the Stanford Research Institute (SRI) CFLOS model. For cloud cover (S), the probability of CFLOS when looking straight up (P_n) is given by

$$P_n = 1 - \frac{S(1 + 3S)}{4} \qquad (2)$$

For CFLOS probabilities at non-zero zenith angles, the sides of clouds (not just their bases) obscure the surface view. Malick et al., assumed that the average cloud height-to-width ratio (b) followed the relation:

$$b = 0.55 - \frac{S}{2} \qquad (3)$$

Equation 4 is then used to obtain the off-zenith CFLOS probabilities, $P(\theta)$:

$$P(\theta) = P_n^{(1+b\tan\theta)} \qquad (4)$$

where θ is the zenith angle shown in Figure 2.

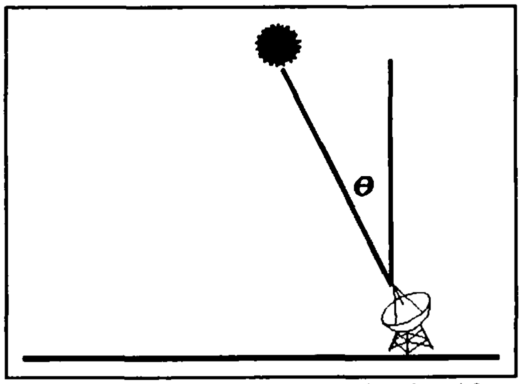

Figure 2. Viewing geometry in cloud-free line-of-sight calculations.

2.2 Cloud-Cover Frequency Distribution. The cloud-cover frequency distribution is obtained from a statistical distribution known as the "Burger Aerial Algorithm" (Burger, 1985). This two-parameter distribution (mean cloud-cover and sky-dome scale distance) is required because many locations, particularly in the U.S., do not report cloud-cover in tenths. Where airways code is used, cloud-cover is reported only as *clear*, *scattered*, *broken*, or *overcast*. The Burger algorithm can use whatever intervals are available to obtain the distribution parameters, and from this the relative frequency (in tenths) of cloud-cover can be inferred. This is then used to determine the relative frequency of eleven categories of cloud-cover given in Figure 3.

Category Number	Cloud-Cover Range	Mean Value
1	0.00 – 0.05	0.025
2	0.06 – 0.15	0.100
3	0.16 – 0.25	0.200
4	0.26 – 0.35	0.300
5	0.36 – 0.45	0.400
6	0.46 – 0.55	0.500
7	0.56 – 0.65	0.600
8	0.66 – 0.75	0.700
9	0.76 – 0.85	0.800
10	0.86 – 0.95	0.900
11	0.96 – 1.00	0.975

Figure 3. Eleven categories of cloud-cover calculated using the Burger Aerial Algorithm.

2.2.1 Data for Barbers Point NAS, Hawaii. As an example of this technique, consider the 00Z January cloud cover for Barbers Point. The Naval weather station reports cloud cover in airways code. The relative frequency distribution of these categories is: clear, 0.8%; scattered, 57.8%; broken, 30.6%; and overcast, 10.8%. The Burger algorithm parameters for this distribution are: mean cloud cover, 0.426; sky-dome scale distance, 0.967 km. The cloud-cover frequency distribution corresponding to these parameters is shown in Figure 4.

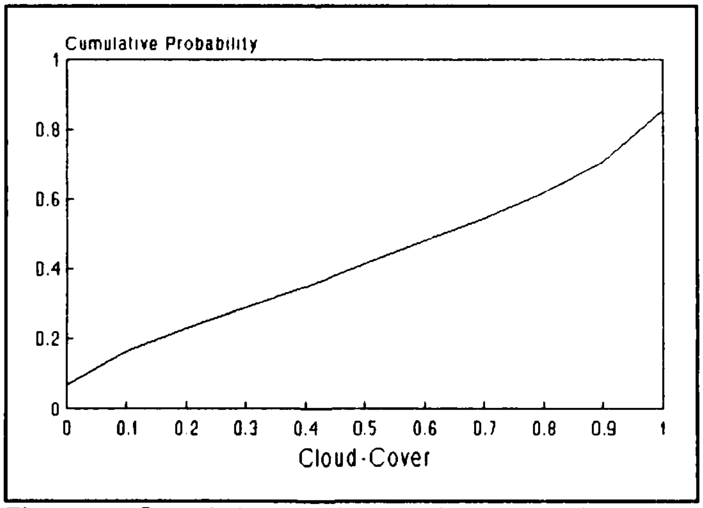

Figure 4. Cumulative distribution of sky cover (using the Burger distribution) for 00Z January at Barbers Point, Hawaii.

2.3 Climatological Probability of CFLOS. The CFLOS relationships discussed earlier are now used to compute the climatological probability of CFLOS as a function of viewing angle at a given location, $P_c(\theta)$. This is done with a weighted average sum of the relative frequency of each cloud-cover interval (f_i) multiplied by its corresponding CFLOS probability $P_i(\theta)$ (obtained from equation 4):

$$P_c(\theta) = \sum_{i=1}^{11} f_i P_i(\theta) \tag{5}$$

Refer again to Figure 3 for the 11 class intervals of cloud cover.

2.4 Sunny Line-of-Sight Probability. The probability of SLOS (P_s) is obtained from CFLOS probabilities by integrating over time:

$$P_s = \int_{t_1}^{t_2} P\,[\theta(t),s(t)]\,dt \tag{6}$$

where $P(\theta,s)$ is the CFLOS probability for zenith angle θ and cloud-cover s; $\theta(t)$ is the solar zenith angle at time t; $s(t)$ is the mean cloud-cover at time t; t_1 is the time of sunrise and t_2 the time of sunset. After obtaining hourly CFLOS probabilities as a function of zenith angle, equation 6 was used to estimate the monthly SLOS probability at Barbers Point. These simulated values are shown in Figure 5. The cumulative distribution of mean monthly SLOS probability (from PTROL data) at Palehua is also shown.

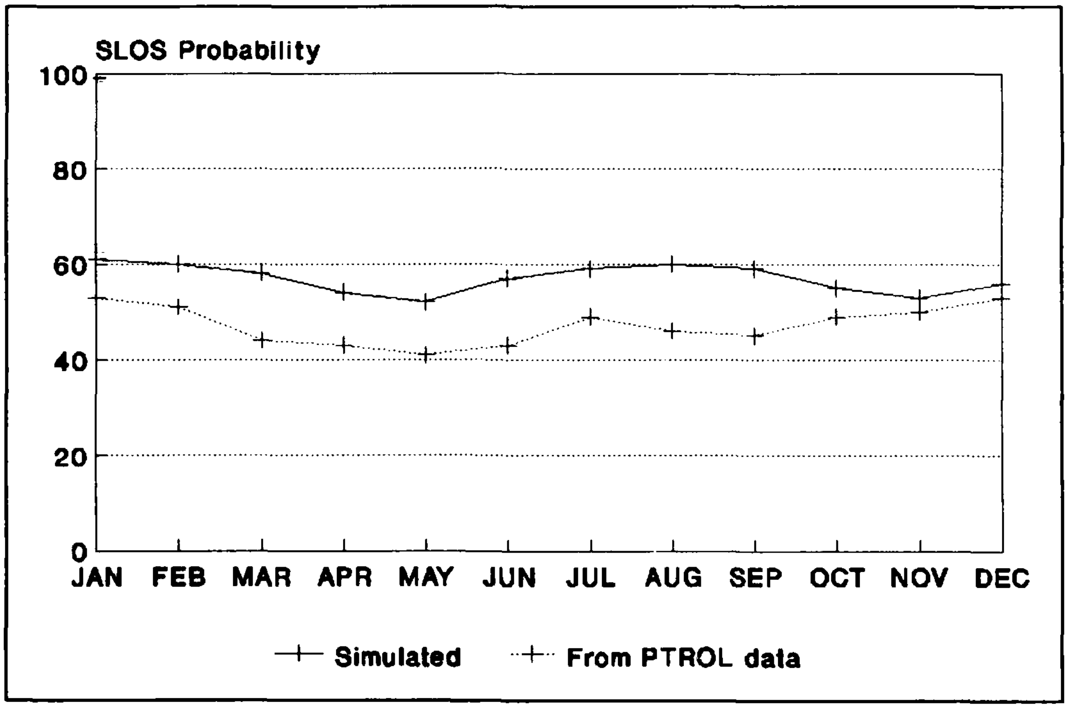

Figure 5. Comparison of sunny line-of-sight calculations from the simulation model and Palehua PTROL data.

2.5 Palehua Sunny Line-of-Sight Data. Finally, we compared the SLOS probabilities estimated for Barbers Point with those calculated for Palehua using the Palehua solar optical site status reports (PTROL data). This database is made up of at least one observational status report a day, including the start time of the observation, reason for start delay, end time, and reason for ending the observation. There are seven different reasons for starting or ending an observation: *weather*, *equipment failure*, *maintenance*, *obstruction*, *power failure*, *miscellaneous*, and *not available* (or *unknown*). The *weather* category includes such phenomena as thunderstorms, blowing sand, and clouds. Every time a solar observation is interrupted, a status report is made. A 5-year period of record (*January 1986 through February 1991*) was used for this study. The database was too large for record-by-record quality control, but records that produced extreme values were reviewed, and some were deleted. From this data, the monthly SLOS probability, P_s, is obtained from:

$$P_S = \frac{T - m}{T} \tag{7}$$

where m is the total number of hours the solar telescope was non-operational on account of weather, and T is the total number of available hours (equal to m plus the number of hours for the month in which the telescope was operational).

3. INTERPRETATION OF RESULTS

3.1 Comparison of Data. For all 12 months, the computed SLOS probabilities derived from the PTROL data were higher than the values estimated from surface observations. The difference is about 10 percent, but somewhat smaller during the winter. The fact that SLOS probabilities at Barbers Point are higher than at Palehua is consistent with expectation. Interestingly, the two curves show nearly identical seasonal trends.

3.2 Problems with the PTROL data. The assumptions in Section 2.5 about how SLOS probabilities were obtained from PTROL data should result in these probabilities being lower than their true values. The times in which the telescope is not operating on account of weather are not solely due to an obstructed line-of-sight. We believe, however that line-of-sight obstructions are responsible for most cases. The remaining cases should total no more than a few percent. This effect would serve to slightly lessen the differences in the two curves shown in Figure 5.

3.3 Conclusions. Despite the limitations discussed, the data in Figure 5 shows good agreement, especially with regard to seasonal trends. It appears that SLOS probabilities at Palehua are typically about 10 percent lower than those at Barbers Point. This is to be expected due to geographical differences. We conclude that the SRI CFLOS model provides realistic estimates of CFLOS probabilities at Barbers Point and that its use in tropical climates is justified.

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GLOSSARY

CFLOS	Cloud-Free line-of-sight
MSL	Mean sea level
NAS	Naval Air Station
POR	Period of record
PTROL	Solar optical sites status reports
SLOS	Sunny line-of-sight
SRI	Stanford Research Institute
USAFETAC	USAF Environmental Technical Applications Center

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